

GPM Plans for Radiometer Intercalibration

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The international Global Precipitation Measurement (GPM) mission led by NASA and JAXA is planned as a multi-radiometer constellation mission. A key mission component is the ability to intercalibrate the T_b from the partner constellation radiometers and create inter-calibrated, mission consistent T_c . One of the enabling strategies for this approach is the launching of a joint NASA/JAXA core satellite which contains a JAXA/NICT provided dual precipitation radar and a NASA provided Microwave Imaging passive radiometer. The observations from these instruments on the core satellite provide the opportunity to develop a transfer reference standard that can then be applied across the partner provided constellation radiometers that enables the creation of mission consistent brightness temperatures. The other aspect of the strategy is the development of a community consensus intercalibration algorithm that will be applied to the T_b observations from partner radiometers and create the best calibrated T_c . Also described is the development of the framework in which the inter-calibration is included in the final algorithm. A part of the latter effort has been the development of a generic, logical structure which can be applied across radiometer types and which guarantees the user community that key information for using T_c properly is recorded.

Key Words: GPM, Radiometer, Intercalibration, 1C

1. Introduction

A key aspect of the Global Precipitation Measurement (GPM) mission is the creation of consistent, at least three hourly global precipitation products from microwave radiometers and radars for both research and realtime. It is obvious that such global coverage cannot be achieved with a single satellite. So, from the very beginning GPM has been based on a constellation of satellites that carry microwave radiometers and are provided by different agencies. They also will fly different orbits. They provide different view angles and different center frequencies. Each will be launched for specific objectives other than participation in the GPM constellation. Each agency will apply calibration and calibration adjustment it deems necessary to accomplish its requirements. Any such adjustments would not necessarily be made to achieve consistency with other radiometers in the GPM constellation.

The objective for GPM is from this collection of data from constellation radiometers to build a GPM consistent and intercalibrated brightness temperature dataset from each constellation radiometer. In creating this consistent level 1 data product GPM will not alter the brightness (or antenna) temperature product provided by the GPM partner to the GPM Precipitation Processing System (PPS).

2. Summary statement of problem

The consistency and intercalibration problem for GPM can be succinctly stated as follows:

- Constellation of satellites with radiometers, each from a different agency/country (i)
- Radiometer \rightarrow Counts \rightarrow Calibration(i) $\rightarrow T_{bi}$
- Each calibration (i) is different and serves the valid purposes of the agency (i)
- HOWEVER, GPM rain algorithms need UNIFORM T_b input (i.e. 1-2 K offset can lead to $\geq 5\%$ difference in rainfall)
- How does GPM create uniform T_b ?

3. Previous work and prototyping

Upon the launch of the joint NASA/JAXA Tropical Rainfall Measuring Mission (TRMM) in November 1997 from Tanegashima Space Center a number of groups have made an effort to combine data from various radiometers into global products in some way using the TRMM Microwave Imager (TMI) and the Precipitation Radar (PR) to “calibrate” the results. The inclined orbit of TRMM lent itself for finding a significant number of matchup between polar orbiting satellites and TRMM. Often this “calibration” or statistical adjustment was done at the retrieval level.

For GPM it was considered important that consistent mission Level 1 T_b products be available from which the retrievals could be made. As pointed in section 2, deviations in T_b can lead to large discrepancies in the precipitation retrievals. The aim was to eliminate error or characterize errors as early in the data production process as possible.

This required addressing many issues (e.g. frequency differences, view angle differences, etc.) that were avoided when attempting the “calibration” by retrieval stage.

In 2005 PPS and a group at Colorado State University began a prototype of intercalibration of radiometer brightness temperatures. The prototype used TMI on TRMM as the “calibrator” instrument and adjustments were made in other radiometers based on this calibrator. The following other radiometers were involved in the prototype: SSM/I (F11, F13, F14, F15), AMSR-E on Aqua, Windsat, and TMI. The details of the approach and access to the data products can be read from CSU website.¹⁾ This effort at times recalibrated a 1B product if it was possible and then applied an adjustment based on the TMI to create a consistent TRMM based (as prototype for GPM) brightness temperature that was designated as T_c or intercalibrated brightness temperature. Some of the prototype products required an adjustment to achieve consistency and for others no adjustment was applied. These “TRMM consistent” T_c were then used to create gridded .25 x .25 degree rain retrievals¹⁾.

A high level description of the prototype process (as it applies to the SSM/I sensors) is as follows:

- Uses TMI as a reference to intercalibrate various SSM/I sensors
- Based on open ocean regions jointly observed within 10 minutes by both TMI and an SSM/I (or other radiometer)
- Also based on radiative transfer calculation to account for channel and view angle differences
- Result is a curve of offsets as a function of T_b for each SSM/I sensor and channel

Another aspect of the prototype was to use the TRMM orbit which starts and ends at the southernmost parts of the orbit. This ensures that no split would occur at the equator and that orbits among the 1C products were be more easily comparable. Besides this re-orbitization the prototype also created a standard logical format for all T_c products. This would facilitate their use as users would always be able to expect to have key parameters in the product and it also facilitated their use by the Level 2 algorithm developers who had the responsibility for coding the retrieval algorithms. A common format greatly facilitates the coding of this algorithm

The objectives of the prototype were to:

- Test the concept of inter-calibrating at the brightness temperature stage
- Create useful scientifically valid products that could actually be used to conduct research
- Create consistent brightness temperature products to facilitate merging and comparisons
- Provide opportunities for the community to comment on the products, the technique and the format

- Provide concrete work for presentations at international conferences to try to obtain consensus on the approach to be used when intercalibrating
- Highlight issues, challenges and future required work.

These prototype objectives were realized and contributed greatly to not only developing the next steps but actually providing the data sets required to get to the next steps. These products are still available and distributed by CSU and PPS.

4. The GPM cross calibration team and process

In 2007, the GPM project scientist established a cross-calibration working group (x-cal) within the Precipitation Measurement Missions (PMM) science team. This group would develop the actual intercalibration techniques and process to be used within GPM. The group decided to start with the prototype work undertaken by PPS and CSU and used prototype data in their studies.

The x-cal team determined that their approach would be a pair-wise comparison between TMI and other target sensors. The first comparisons were between TMI and Windsat and extensive investigation was done comparing these two sensors. It soon developed that the team divided into 4 subgroups each with a different approach to comparing the two sensors. An important aspect of the study approaches used was that in spite of adequate standards for such intercalibration it was still required that the absolute calibration be as accurate as possible. Whichever analysis techniques were used by the subgroups in doing the pairwise comparisons, all the results were to be examined using a double difference approach that minimized the impacts of assumptions. In this approach the differences for each channel between the parameters for each sensor in the pair was calculated. This difference was then to be subtracted from the actual observed value of the parameters for each channel of the two sensors. This double difference would then yield the calibration difference between the two channels on the two target sensors.²⁾ This double differencing approach yields comparable values among the different techniques used to analyze two sensors.

An important outcome of the x-cal teams research was the discovery of a time varying bias in the TMI brightness temperatures. It was surmised that the discovered time-of-day dependent variation was caused by changes in the TMI reflector physical temperature over the course of an orbit. During the daylight part of the orbit the reflector was heated and during the Earth eclipse part of the orbit it cooled.³⁾ The effectiveness of the process for intercalibration process was demonstrated by this finding. However, not only did the team find this bias, it also developed a table which used on a scan by scan basis during the production of the TMI brightness temperature product adjusts for this bias.⁴⁾ TRMM v7 1B11 products will contain these bias corrections. So, the GPM intercalibration efforts have already lead to an improvement in consistency in current sensors including TRMM TMI. This bodes well for the application of such

techniques for establishing a consensus inter-calibration approach based on GMI for the GPM constellation satellites. Given that errors of 1° K can lead to errors greater than 5% in the precipitation retrievals, the approach helps ensure that the T_c used by the retrieval algorithms will contain the most consistent brightness temperatures possible.

The x-cal work pointed out some key aspects of intercalibration needs. It was determined that as much information about the sensor and its behavior over the years was absolutely imperative for understanding its radiometric information. This often proved difficult with early sensors such as the SSMI series. It was often difficult or impossible to locate the necessary information. This resulted in the team determining that during GPM, each sensor would be assigned to a team subgroup who would provide the expertise for that sensor. While it is planned that the sensor provider would volunteer to provide a x-cal team member to undertake this effort, should this not be the case a team member would still be assigned the sensor. This difficulty in tracking information for sensors also led to the decision to include a special product for GMI which would have an orbit number of 0. This product would include:

- Calibration information for the instrument
- Operation history including outages, maneuvers, calibration changes, etc.
- The 1B Algorithm Theoretical Basis Document (ATBD) that provides the approach for calibration
- The geolocation Algorithm Theoretical Basis Document that provides the details of how the pixels in the product were geolocated
- All other information that indicates changes in the instrument and its operation

All information in this product would be put in an archive format (Linux tar) and be available to order or download. This would provide maximum information about GMI and its operation even when the individuals involved with that effort were gone or working on other sensors.

Another lesson learned from these inter-calibration effort was the need to obtain the least processed data possible. To do an unbiased comparison it was often necessary to back out the calibrations applied by sensor data producers. This was very difficult when appropriate information was lacking. This led to the desire to obtain T_a from partners so the x-cal group could apply their own calibration approaches to obtain consistent T_b . It was recognized that this would not always be possible and in the event it wasn't then the x-cal team members responsible for the sensor would need to provide the necessary information to back out calibrations. This also led to the development of a GMI product which would contain only T_a and append the calibration rather than apply it. This base product would also include all instrument and spacecraft information (e.g. thermistor values, noise diode values, etc.) that could be used to help characterize not only the instrument but also the environment that the sensor was operating. This

product was not intended to be generally distributed but would prove of interest to any scientist interested in intercalibrating sensors. The decision was also made to create a base product for each GPM constellation radiometer and to begin intercalibration processing (1C) from the base product rather than from the partner provided T_b product. It was recognized that for some radiometers the base product would be essentially a reformatted T_b product. However, the x-cal team member responsible for the sensor would attempt to provide as much of the desired base content as it was possible to discover.

Another outcome of the extensive intercomparisons carried out by the x-cal group was the determination that incidence angle information must be included in the base files and even in the T_c products that are produced. Incidence angle is an important factor when comparing two different sensors and can have a substantial impact on the ultimate brightness temperature. For multiple swath sensors including incidence angles for each pixel would lead to larger products than had originally been intended but it was clear that the need for the information outweighed the increase in size.

Out of the work from the prototype and the x-cal team a general process for intercalibration during GPM was determined:

- Each sensor must have a team member who was the "expert" for the sensor. This individual would be able to answer questions about the sensor, its behavior, and its operation
- Pairwise comparisons of sensors would be carried out using different approaches but all using the "double differencing" reporting for each of the GPM constellation radiometers.
- For GPM the "calibrating" sensor would be GMI on the core satellite but analysis would determine how this would be applied
- An appropriate "adjustment" table would be provided to PPS for each sensor. At launch no adjustments would be made
- PPS would re-orbitize the sensor orbit to the S-S orbit of the GPM core using either Two-line element files or internal information
- PPS would create a base file format for the sensor data
- PPS would apply the x-cal provided "adjustment" to create consistent T_c .
- PPS would create the T_c product in the standard 1C format.

Matchups of crossings between the GMI core and the partner radiometer would be carried out and analyzed routinely. These results would be available for the x-cal team to ensure that the adjustments were being correctly and consistently applied. In addition, this matchup analysis would show the trending of the inter-calibration as well as point out changing sensor behavior. This information is key

to making the necessary adjustments in the intercalibration values. Such matchup analysis would be conducted and monitored at PPS but changes reported to the x-cal team as well as directly to the team member responsible for a particular sensor. This process recognizes that inter-calibration is not a "one-time" activity but one that needs to be monitored and perhaps to be modified.

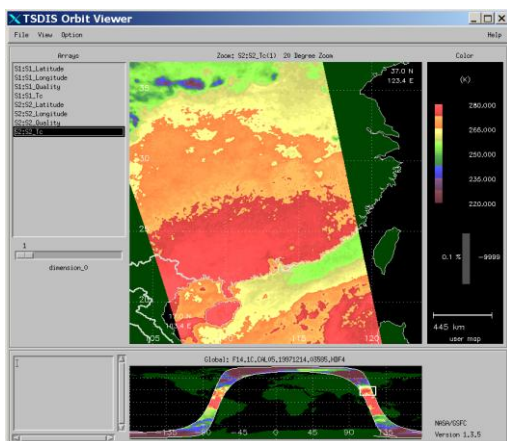
The process also identifies the responsibilities for the various steps. X-cal has responsibility for the analysis and determination of any required sensor calibration adjustments required to keep a sensor consistent within GPM. The X-cal team will also provide the algorithm and/or the adjustment tables necessary to carry out a sensor intercalibration. The data system has the responsibility for integrating these algorithms/tables into an overall level 1C code that re-orbitizes partner products as necessary, reads the base input, applies the x-cal provided adjustment, and writes out the final 1C product in the accepted format. The matchup/monitoring software are also the responsibility of PPS to provide. However, the analysis of the results of this software are the x-cal team responsibility. This division of labor within the overall intercalibration process ensures the best intercalibrated products for GPM.

5. Format for intercalibrated T_b (T_c)

While a detailed description of the 1C format is not a purpose of this paper, a description of the general logical format is in order as it is a consequence of the prototype and x-cal intercalibration activities described in the paper. The 1C product for any GPM radiometer product contains intercalibrated brightness temperatures T_c and only that information necessary to use and understand them correctly. Parameters often seen in 1B products that are really parameters of use for the algorithm developers are not intended for inclusion in the GPM 1C. An important factor in 1C product design was to keep it as small as possible for easy network transport.⁵⁾

Figure 1) -Prototype SSMI F14 1C

As pointed out in the paper, one step in the creation of the GPM 1C product is the re-orbitizing of a partner



radiometer to the South-South orbit adopted for the GPM

core.

Figure 1 provides an example of an SSMI F14 1C product that shows the new South-South orbit from the polar orbiting. This prototype image not only shows the orbitization but also how few parameters were actually considered essential for a 1C product. These early decisions have been largely vindicated by the x-cal team using these products as well as by other researchers. Since that prototype the incidence angle was included in the logical format for GPM 1C products.

Generally, the number of swaths in the product are dependent upon the individual instrument. For example in the case of TMI there is only 1 swath type whereas in SSMI there are two swath types: one for the lower frequencies and one for the higher frequencies. GMI will have two swath types. Some instruments may have more. But, however many swaths the type of information maintained for the swaths will be the same.

Each swath structure has:

- Header including sensor geometry
- Scan time
- Latitude
- Longitude
- incidence angle
- Spacecraft status and location
- Quality of T_c
- T_c

This presents the core information that users and algorithm developers can always count on being in a 1C product. The parameters selected were a result of the prototype and x-cal activities described in this paper. Additional parameters may be included if further research warrant it. The general philosophy will always dictate that only the absolutely necessary parameters should be included. Parameters required by the x-cal team for algorithm development or monitoring are more likely to be added to the base file format than to the 1C format.

6. Summary

The GPM project has developed the concept of products that contain inter-calibrated brightness temperatures that are mission consistent across constellation radiometers. These products will be the main brightness temperature products distributed both in production and near-realtime.

A process for inter-calibration has been developed that is based on pair-wise comparison of brightness temperatures from constellation radiometers. This process is an outgrowth of the early prototype work using TMI as the surrogate for GMI and further honed by the extensive comparisons carried out by the x-cal team. In addition the process led to the discovery of time-dependent biases in TMI brightness temperatures and also led to the development of consistent

TMI products. This helps to vindicate that the process developed can lead to consistent, well-calibrated T_b for GPM radiometers thereby leading to greatly improved retrievals.

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